A Processing of OFDM Signals from UAV on Digital Antenna Array of Base Station in Conditions of Jammers

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ABSTRACT

A new two-stage digital processing of OFDM signals received from UAV in digital antenna array (DAA) is described in this report with the purpose of effective elimination of jammers influence. This technology can be use for Secure Wideband Networking Waveform (WNW).

In this report is described a two-stages OFDM signals processing in digital antenna array (DAA) of base station with the purpose of effective elimination of jammers influence in UAV communications (fig. 1) [1]. The essence of it is an intermediate estimation of amplitudes of OFDM signals on an exit of digital beamforming procedure. It allows separating the signals of jammers in each readout time for use in the further processing only a part of a amplitudes vector, which corresponds to UAV's data signals. It is also supposed, that angular coordinates of sources of jammers are determined before the beginning of measurements, and also, that directions of data signals arrival from UAV are precisely known.

If this information is full and given, we can present a vector of voltage U for OFDM signals on exit of digital beamforming in separate moments of readout time as

$$U = QW + n, \tag{1}$$

where $Q = [Q_S \mid Q_P]$ – block matrix of values DC of secondary spatial channels in directions on UAV sources (a block Q_S) and on jammers signals (block Q_P); for general case of M test sources and J of jammers a matrix's blocks of a directivity characteristics of secondary spatial channels in azimuth planes can be written as

$$Q_S = \begin{bmatrix} Q_1(x_1) & Q_1(x_2) & \cdots & Q_1(x_M) \\ Q_2(x_1) & Q_2(x_2) & \cdots & Q_2(x_M) \\ \vdots & \vdots & \vdots & \vdots \\ Q_R(x_1) & Q_R(x_2) & \cdots & Q_R(x_M) \end{bmatrix}, \quad Q_P = \begin{bmatrix} Q_1(x_1) & Q_1(x_2) & \cdots & Q_1(x_J) \\ Q_2(x_1) & Q_2(x_2) & \cdots & Q_2(x_J) \\ \vdots & \vdots & \vdots & \vdots \\ Q_R(x_1) & Q_R(x_2) & \cdots & Q_R(x_J) \end{bmatrix},$$

where $x_{m(j)}$ – a generalized angles coordinates of UAV or jammers with respect to DAA normal, $x_{m(j)} = \frac{2\pi}{\lambda} d\left(r - \frac{R-1}{2}\right)\sin\theta_{m(j)}$, λ – wavelength of UAV signals or jammers carrier, d – the distance between array's elements of DAA, R – number of array's elements, $\theta_{m(j)}$ – the angles coordinates of test sources or jammers with respect to DAA normal,

$W^T = [W_S \mid W_P]$ – a block vector of the generalized amplitudes of OFDM signals (a block W_S, which contains the information about of directivity characteristics (DC) of antenna elements), and of jammers signals (a block W_P); "T" – a symbol of operation of transposing; n – a vector of noise's voltage.

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For the OFDM signals and jammers signals separation during the forming of optimum estimation of amplitudes vector $\hat{W} = \left(Q^T Q\right)^{-1} Q^T U$ are calculated only the segments of a vector $\hat{W}$, corresponding data of signals OFDM, that is the block W_S. Thus a segment of a vector of estimations of amplitudes jammers signals (block W_P) is not formed at all.

A correction of the reception channels characteristics can be used for errors minimization of digital beamforming system with non-identical channels of antenna arrays [2].

At the second stage of processing of estimations of amplitudes of the signals, which are taken by means of moments sequence of readout time, should be executed a procedure of fast Furrier transformation (FFT), that allows to synthesize the frequency filters, which are necessary for spectral selection of OFDM signals carriers, and also they are necessary for final estimation their amplitudes. It is also should be mentioned, it is essential, that 2-stage strategy of processing does not demand formation of frequency filters for all DAA reception channels. It cardinally simplifies processors' speed requirements and reduces operative memory volumes requirements and data transmission lines throughput requirements.

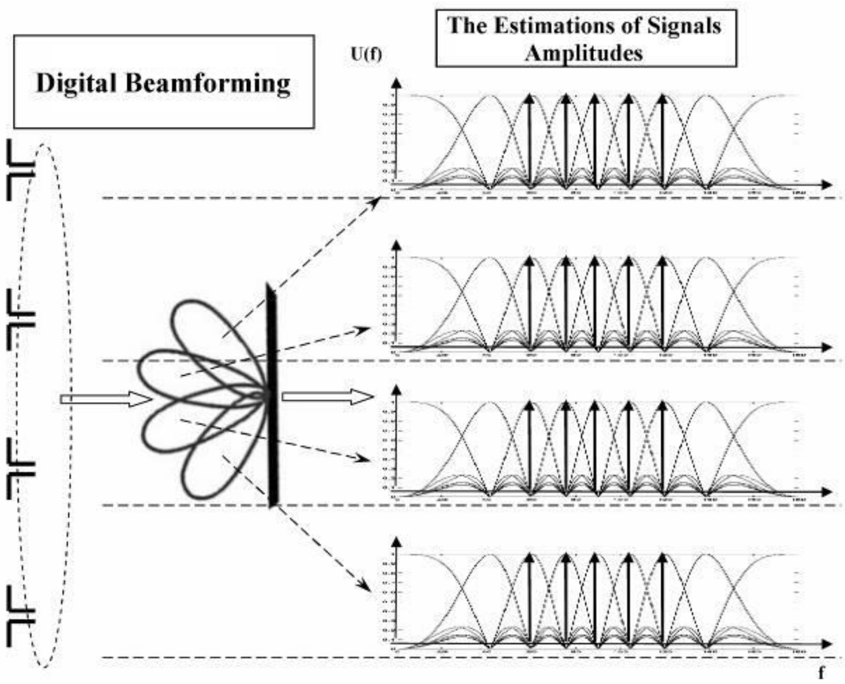

Figure 1: Two-stage digital processing of OFDM signals

If a vector of voltage U for OFDM signals on exit of digital beamforming in separate moments of readout time is presented as (1), that expression for Cramer-Rao low bound (CRB) for dispersions estimations of a vector of the generalized amplitudes can be written in the form of

$$\sigma_W^2 \geq \sigma_n^2 diag\left[Q^T Q\right]^{-1}, \quad (2)$$

where σ_n^2 – a dispersion of noise in separate moments of readout time on exit of the secondary spatial channel, $diag[Z]$ – a vector made of diagonal elements of a matrix Z.

Or in recalculation to a dispersion of noise on an exit of the analog-to-digital converter:

$$\sigma_W^2 \geq \sigma_{ADC}^2 \cdot R \cdot diag\left[Q^T Q\right]^{-1}, \quad (3)$$

where R – a dimension of spatial FFT (a number of DAA elements), σ_{ADC}^2 – a dispersion of noise on an exit of the analog-to-digital converter.

On conditions that responses of frequency filters after FFT can be given in the form of

$$\hat{W}_{FFT} = FA + n_W, \quad (4)$$

where $\hat{W}_{FFT}$ – a vector of voltage of responses of frequency filters,

$F = \begin{bmatrix} \dot{F}_1(\omega_{11}) & \cdots & \dot{F}_1(\omega_{T1}) \\ \vdots & \cdots & \vdots \\ \dot{F}_G(\omega_{11}) & \cdots & \dot{F}_G(\omega_{T1}) \end{bmatrix}$ – a matrix of amplitude-frequency response (AFR) $\dot{F}_g(\omega_{tm})$ of G frequency filters synthesized as a result of operation FFT for R identical reception channels; A – a vector of amplitudes of signals, which contains the information about of directivity characteristics of antenna elements for frequency ω_{tm}, n_W – a vector of noise voltages,

as dispersions of estimations for a vector of the amplitudes, which correspond to CRB, it is necessary to consider expression

$$\sigma_A^2 \geq \sigma_W^2 \cdot N \cdot diag\left[F^T F\right]^{-1}, \quad (5)$$

where N – dimension of FFT, used for synthesis of frequency filters.

Substitution of expression (2) into (5), allows us to present a final ratio for CRB estimations of signals parameters within the limits of two-stage procedures.

When signals coming from different directions, have an identical grid of frequencies, the borders for dispersions can be written in the form of:

$$\sigma_A^2 \geq \sigma_n^2 \cdot diag\left[Q^T Q\right]^{-1} \otimes \left(N \cdot diag\left[F^T F\right]^{-1}\right), \quad (6)$$

where $\otimes$ – a symbol of Kronecker products of matrices,

or at recalculation to a dispersion of noise on an output of the analog-to-digital converter:

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot diag\left[Q^T Q\right]^{-1} \otimes \left(N \cdot diag\left[F^T F\right]^{-1}\right). \quad (7)$$

If the grid of frequencies is unique on each angular direction, estimations of dispersions (6) and (7) should be copied in the form of:

$$\sigma_A^2 \geq \sigma_n^2 \cdot \left(diag\left[Q^T Q\right]^{-1}\right)_r [\otimes] \left(N \cdot diag\left[F_r^T F_r\right]^{-1}\right), \quad (8)$$

$$\sigma_A^2 \geq \sigma_{ADC}^2 R \cdot \left(diag\left[Q^T Q\right]^{-1}\right)_r [\otimes] \left(N \cdot diag\left[F_r^T F_r\right]^{-1}\right), \quad (9)$$

where $[\otimes]$ – a symbol of block Kronecker product of matrices, F_r – a matrix of AFR for the frequency grid, which corresponds to *r*-th a direction of arrival of signals, $(diag[M])_r$ – *r*-th element of a vector $diag[M]$.

For comparison it is necessary to provide the CRB estimation, which corresponds to one-stage estimation, using the following expression:

$$\sigma_A^2 \geq \sigma_{nW}^2 \cdot diag\left[P^T P\right]^{-1}, \tag{10}$$

where σ_{nW}^2 – a dispersion of noise on exits of frequency filters, $P = Q[\otimes]F$ – the signal's matrix, which elements are formed by products of values AFR of frequency filters and DC of secondary spatial channels.

In recalculation to dispersions of noise on an exit of the analog-to-digital converter expression (10) can be copied in the form of:

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot N \cdot diag\left[P^T P\right]^{-1}. \tag{11}$$

$$\sigma_A^2 \geq \sigma_{ADC}^2 \cdot R \cdot N \cdot diag\left[(Q[\otimes]F)^T (Q[\otimes]F)\right]^{-1}. \tag{12}$$

The taken result allows us to conduct the comparative analysis of accuracy one- and two-stage procedures of demodulation that is the purpose of the further researches.

In this time the author have a result only for one-frequency and two-frequency OFDM signals (fig. 2, 3, where σ_A is a mean-square error (MSE) of amplitudes estimations, Δf – a frequency's interval).

Using the result of modeling it was possible to confirm validity of identity:

$$diag\left[Q^T Q\right]^{-1} \otimes \left(diag\left[F^T F\right]^{-1} \right) = diag\left[(Q \otimes F)^T (Q \otimes F)\right]^{-1},$$

that exists on the assumption of full orthogonally of signals on frequency and a direction of arrival.

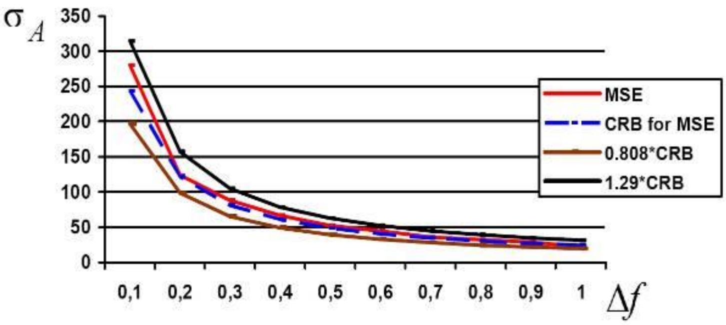

Figure 2: A mean-square error (MSE) of amplitudes estimations at one-stage measurement for 16-elements DAA, two-frequency OFDM's signals and full orthogonally of 2 signals at a direction of arrival (one direction of arrival is a jammer)

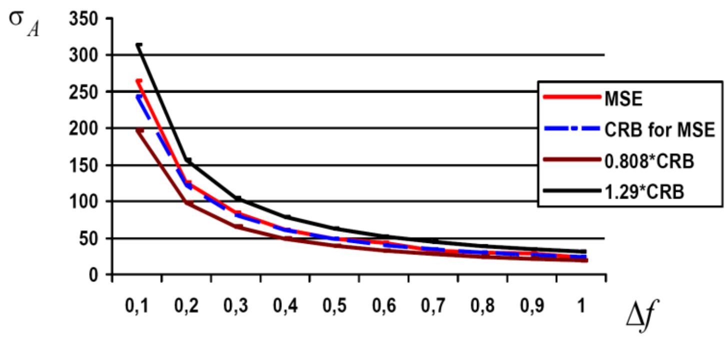

Figure 3: A MSE of amplitudes estimations at two-stage measurement for 16-elements DAA, two-frequency OFDM's signals and full orthogonally of signals at a direction of arrival (one direction of arrival is a jammer)

If non-orthogonally frequency of signals (the case of N-OFDM signals [3]) and non-orthogonally angular coordinates are used, 2-stage estimation with different matrixes AFR gives more exact estimations, than with use of common matrix AFR hence, and generally it is possible to write:

$$diag\left[Q^T Q\right]^{-1} \otimes \left(diag\left[F^T F\right]^{-1} \right) \geq diag\left[(Q \otimes F)^T (Q \otimes F)\right]^{-1}.$$

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